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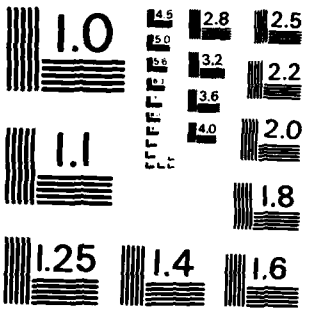

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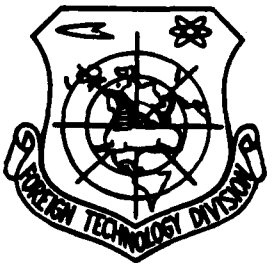
by

V.A. Kochelan, Yu.A. Kukibnyy



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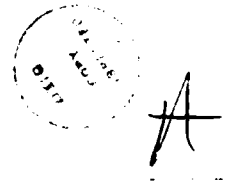

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В в	*В в*	V, v	Т т	*Т т*	T, t
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К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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THE POSSIBILITY OF AMPLIFYING INFRARED RADIATION BY HIGH-PRESSURE REACTING GAS

V.A. Kochelan, Yu.A. Kukibnyy

Being intensely investigated at present are infrared chemical lasers in which the process of the stimulated light emission is preceded by a chemical reaction, as a result of which populated molecules are inversely formed [1]. Usually used in such type of lasers are reacting gases of low pressure, since with an increase in pressure the rate of deactivation of the excited molecules is increased.

Noted in this work is the possibility of amplifying the infrared radiation by a reacting gas in cases when serving as the working transition is the phototransition of a pair of reacting molecules, which lead to a change in their translational-rotational motion with an unchanged electron state. It is found that in such cases reacting gases of high pressure can be used for the light amplification. This is the special feature of the considered mechanism of light

amplification and a number of others are analogous to properties of the chemical laser on electron phototransitions proposed in work [2].

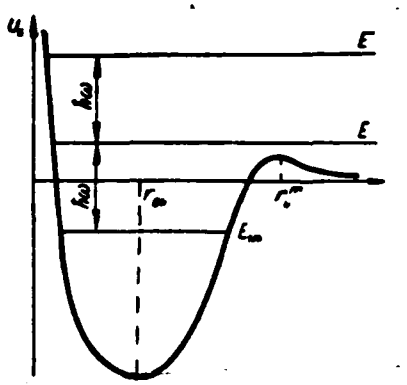

Figure.

For definiteness, let us examine the reaction of the recombination of atoms of two kinds. A pair of reacting particles, in approaching, moves in the effective field of the electrons and nuclei $U_k(r) = U_0(r) + \frac{\hbar^2 k(k+1)}{2\mu r^2}$ with an energy of the relative motion E>0 (k - rotational quantum number, μ - normalized mass, see the figure). At reciprocal distances $r \approx r_{0k}$ there appears the dipole moment p(r), and the phototransition becomes possible. In the case of collisions with $E < \hbar\omega$ (ω - light frequency), the emission of a quantum leads to the formation of a stable molecule with energy $E_{vk} = E - \hbar\omega < 0, v$ - the oscillating quantum number. This phototransition is more probable than the absorption $E \to E + \hbar\omega\ (E > 0)$ and radiation $E \to E - \hbar\omega$ (when $E > \hbar\omega$), since for it the final states of the transition are characterized by localized wave functions. Considering the

distribution of atoms with respect to energies, we can be sure that in a gas with temperature T the emission processes predominate over the absorption processes when $\hbar\omega > T$ (T - temperature in energy units). Below we will assume that this condition is fulfilled. If, moreover, the rapid relaxation of the excited levels E_{vk} is ensured, then the light amplification factor in the recombining gas is $\alpha>0$. In cases when we can disregard the absorption by bound molecules, where $\alpha = a n_1 n_2$, n_1 and n_2 are concentrations of the recombining atoms. Coefficient a is usually [3] expressed in terms of matrix elements $p_{12}(\omega) = (E_{vk}, k \pm 1 | p(r) | E, k)$. The latter, for transitions between the quasi-classical states, depend on the difference $E - E_{vk} = \hbar\omega$ [4]; the dependence of k on E_1, E_2 separately is insignificant. Let us give the expression for a in the following cases. When $T \ll \hbar\omega_{vk} = E_{v+1,k} - E_{vk}$ the phototransitions should be observed mainly on rotational sublevels of one oscillating state $E_{vk} \approx E_{v0} + B_v k(k+1)$, for which $E_{v0} \approx \hbar\omega$, then

$$a \approx \frac{(2\pi)^{7/2}\hbar^4\omega_{v0}\omega}{3c\mu^{3/2}T^{1/2}B_v} |p_{12}(\omega)|^2. \qquad (1)$$

In the case of $T > \hbar\omega_{vk}$ phototransitions are observed on the many oscillating levels, and the expression for a takes the form

$$a \approx \frac{(2\pi)^{7/2}\hbar^4\omega_{v0}\omega}{6c(\mu T)^{3/2}} \sigma(T) |p_{12}(\omega)|^2. \qquad (2)$$

Factor $\sigma(T)$ appears due to the presence of the centrifugal barrier in the potential energy $U_k(r)$ [5] and is determined by the equality

$$\sigma(T) = \sum_k (2k+1) \exp\left[-\frac{U_k(r_k^m)}{T}\right],$$

r_k^m - the position of the maximum of the barrier (see the figure).

The matrix element $p_{1,2}(\omega)$ can be evaluated, having used the Morse model:

$$U_0(r) = U_e[e^{-2\beta(r-r_e)} - 2e^{-\beta(r-r_e)}].$$

For the most urgent case $\hbar\omega \ll U_e$ the expression for $p_{1,2}(\omega)$ can be found from the formula of work [6]:

$$|p_{12}(\omega)|^2 \approx \left(\frac{dp}{dr}\Big|_{r_e}\right)^2 \frac{1}{\beta^2\hbar^3\omega^2} e^{-\frac{2\omega}{\omega_0}}. \qquad (3)$$

where $\omega_0 = \sqrt{\frac{\beta^2 U_e}{2\mu}}$ is the frequency of oscillations of the main state. Hence it follows that the most probable is the phototransition at frequencies $\omega \leq \omega_0$. In the same model it is possible to find $\hbar\omega_{v0} \approx 2\sqrt{\frac{\beta^2\hbar^2\omega}{2\mu}}$.

If in the working volume there are reaction products, then the light amplification factor is written in the form

$$\alpha = an_1n_2\xi. \qquad \xi = 1 - \frac{\delta m}{n_1n_2}\left(\frac{\mu T}{2\pi\hbar^2}\right)^{3/2}. \qquad (4)$$

where $\delta = T/B_v$ when $T > \hbar\omega_{vk}$ and $\delta = 1/\sigma(T)$ when $T < \hbar\omega_{vk}$; m - concentration of the molecules - reaction products in states with energies $|E_{vk}| < \hbar\omega$. In conditions of the recombining gas, these states are populated with the speed of the thermal recombination reaction kn_1n_2. If their destruction is ensured with a rate of gm molecules per unit time, then the condition of amplification $\xi > 0$ takes the form

$$\frac{g}{k} > \delta\left(\frac{\mu T}{2\pi\hbar^2}\right)^{3/2}. \qquad (5)$$

Under a pressure of the order of atmospheric, a sufficient rate of deactivation of the nonequilibrium populated levels with $|E_{vk}| < \hbar\omega$ can be ensured by the inelastic collisions in the gas,

since for these levels $\hbar\omega_{0k} \lesssim T$, the deactivation occurs as a result of one or several gas-kinetic collisions. It is essential that here with the growth in the pressure, the necessary condition of light amplification (5) is not deteriorated, since g and k are proportional to the total concentration of particles in the gas N; at the same time $\alpha \sim N^2$. Consequently, the effectiveness of the examined light amplification mechanism is increased with an increase in pressure.

Let us estimate a and α for the specific recombination reaction $Li+H \rightarrow LiH+\hbar\omega$. For the molecule LiH, it is possible to assume that $\hbar\omega_0 = 1400$ cm^{-1}, $\left(\frac{dp}{dr}\right)_{r_0} = 0{,}3e$, e - the electron charge [7]. Assuming that T=500°K and $\omega=\omega_0/2$, we can find that $\hbar\omega_{0k} < T$, so that it follows to use formula (2). Let us estimate the value of σ by assuming that $U_0(r)$ has the form of the Morse potential with parameters of the basic electron state LiH, and, as result, we get $\sigma = 1.1 \cdot 10^3$, $a = 2.5 \times 10^{-41}$ cm^5. For g we take the value A determined by the cross section of the usual gas-kinetic collision $\frac{g}{N} = 10^{-10}$ s^{-1}; then from (5) there follows the condition which must be satisfied by the rate of the thermal recombination reaction: $k < N \cdot 10^{-31}$ cm$^6 \cdot$s^{-1}. This inequality is apparently fulfilled, since usually for the three-particle recombination reactions $k/N \lesssim 10^{-33}$-10^{-32} cm$^6 \cdot$s^{-1}. Assuming that $\xi=1$; $n_1=n_2=10^{19}$ cm^3, for the light amplification factor we get $\alpha = 2.5 \cdot 10^{-3}$ cm^{-1}. It is evident that the light amplification factor is sufficient for carrying out the laser generation.

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Institute of Semiconductors of the Academy of Sciences of the USSR, Kiev - - Received 29 June 1971

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